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Trigonometric Function in Application of Proptosis Measurement

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1. Abstract:

1.1. Background: To explore the accuracy of trigonometric function in proptosis measurement.

1.2. Methods: It was a none-inferiority trial. In our research, 120 eyes of 60 patients without eye diseases or injury were included. The patients came to our clinic from February, 2020 to June, 2020. The absolute values of proptosis were measured by trigonometric function and computed tomography. Medcalc software version 19.0.4 was used to conduct statistical analysis. And the differences between the two methods were showed by Bland and Altman plot.

1.3. Results: The absolute value of proptosis measured by computed tomography and trigonometric function showed good correlation. Further analysis showed that a 95% limit of agreement was -0.53 to 0.60 mm in right eye and -0.46 to 0.55 mm in left eye between computed tomography and simple trigonometric function. In addition, a 95% limit of agreement was -0.49 to 0.60 mm in difference of both eyes between the two methods. All points were lower than 5% in Bland and Altman plots.

1.4. Conclusions: Compared with computed tomography, trigonometric function has a good consistency in proptosis measurement. It means that the new method is feasible in clinical practice when measuring proptosis. With the development of non-contact intelligent measurement software and the continuous improvement of measurement accuracy, a non-invasive, simple and inexpensive measurement mode will come true based on the theory of trigonometric function.

2. Background

Proptosis is one of the most common symptoms of orbital diseases. Both increasing of orbital content and shrinkage of orbital cavity can lead to proptosis. The opposite sign of proptosis is known as sunken eyeball. Sunken eyeball is not as common as proptosis, but it is more diagnostic than proptosis. The measurement of proptosis is an important part of orbital diseases. We know that the value of proptosis refers to the vertical distance from the anterior aspect of lateral orbital margin to the apex of the cornea. It includes comparative value, absolute value and relative value. [1, 2] The measurement of proptosis is essential in diagnosis and treatment of orbital disease.

At present, exophthalmometers are used for measuring proptosis broadly. Hertel exophthalmometer is mostly used to measure poptosis among different kinds of exophthalmometers [3-5]. Nevertheless, some studies demonstrated that reproducibility (interobserver variation) and repeatability (intraobserver variation) were poor in proptosis measurement with Hertel exophthalmometer [4-6]. The reliability of Hertel exophthalmometer reduced because of interobserver and intraobserver variations [6-9]. Besides, it is well-known that orbital Computed Tomography (CT) has the highest accuracy in proptosis measurement, [10] but it is with high radiation and price.

In our research, we propose a new way of trigonometric function to calculate the proptosis. Compared with the previous methods, we try to find out a simple, cheap and non-contact way so as to finish the proptosis measurement.

3. Methods

3.1. Objects

This was a none-inferiority trial. The patients who went to the ophthalmic clinic of Peking University Shenzhen hospital from February 2020 to June 2020, were checked with routine eye examinations to exclude orbital trauma, congenital dysplasia, strabismus and myopia. Three dimensional CT examination of the orbit was performed in 60 patients, including 25 males and 35 females with an average age of 38.3 (range 20 to 67). The absolute values of proptosis of both eyes were measured by CT method and trigonometric function method, and the relative values of proptosis between both eyes were also calculated.

3.2. Experimental methods and technical control

The absolute values of proptosis were measured by CT. When measuring, the subjects were in supine position and their eyes were closed. The orbital continuous CT (SOMATOM PIUS 4 POWER) scan was performed with 1 mm slice thickness. The horizontal axial images of orbital CT scan were selected and the measurement image standard was as followed: the center of lens (the midpoint of lens axis and longitudinal axis) and intraorbital segment of optic nerve were displayed on the same horizontal plane while bilateral eyeballs were symmetrical and the outer margin of orbits were at the lowest point. In the standard image, the outer margins of both orbits in the soft tissue window were linked to make a line. The vertical line crossing crystal center from the farthest point of front arc of eye ring was made. The length of the vertical line was the absolute value of proptosis (Figure 1). The mean value was calculated by the same examiner for 3 times examination. The absolute values of binocular proptosis were measured and the relative difference between the two eyes was also calculated.

Proptosis measured by CT in (Figure 1) was transformed into the mathematical calculation model in (Figure 2). Point A and B were the lowest points of bilateral lateral orbital margins, and C was the corneal apex. The absolute value of proptosis was the vertical distance from point C to line AB. In plane triangle ABC (Figure 2), the lengths of sides were BC = a, AC = b and AB = c, respectively. According to trigonometric function, cosA was calculated with (b2+c2-a2)/2bc and sinA was calculated with √1-(cosA)2. In right-angle triangle ADC，length side of CD was calculated with sinA * b and it could also be calculated with b * √1-[(b2+c2-a2)/2bc]2. Thus, the length side of CD was calculated with sinA * b = b * √1-(cosA)2 = b * √1-[(b2+c2-a2)/2bc]2. The length of CD was defined as proptosis.

Trigonometric function was used to calculate the absolute value of bilateral proptosis. The measurement process was showed in (Figure 3). The patient was in supine position and the lowest points of bilateral orbital margin were marked with marker pen. Procaine hydrochloride eye drops (Alcon registration, Registered number H20160133) were used to relieve the uncomfortable feeling. The A-scan probe was sterilized with 70% alcohol and fixed with one foot of compass (A-scan probe was used to contact the cornea when measuring and it was helpful to guide the patient to look straight ahead by emitting infrared rays). The A-scan probe was placed vertically at the corneal apex (the infrared emission point of the probe was coincided with the corneal apex). Another foot of the compass was placed at the homolateral side of the orbital margin marked point. The distance between infrared emission of A-scan probe and another foot of compass was measured with a ruler and the distance was considered as AC = b (mm) (Figure 3A). Next, A-scan probe was placed vertically at the corneal apex (the infrared emission point of the probe was coincided with the corneal apex) while the other foot of compass was placed at the heterolateral orbital margin marked point. Similarly, the distance BC = a (mm) which was defined from the infrared emission point of the A-scan probe to the other foot of compass was measured, too (Figure 3B). Two feet of compass were placed at the marked points of orbital margin and the distance between the two feet of compass was measured with a ruler. The distance was considered as line AB = c (mm) (Figure 3C and 3D). The mean value was obtained by the same examiner for three consecutive measurements. The results were showed as AB= c (mm), AC = b (mm), BC = a (mm). In triangle ABC, CD = sinA * b = b * √1 - (cosA) 2 = b * √1 - [(b2 + c2-a2) / 2bc] 2, and CD is the absolute value of proptosis. The calculation formula was set up in Excel to simplify the calculation process of proptosis. The data was recorded as the trigonometric function methodology.

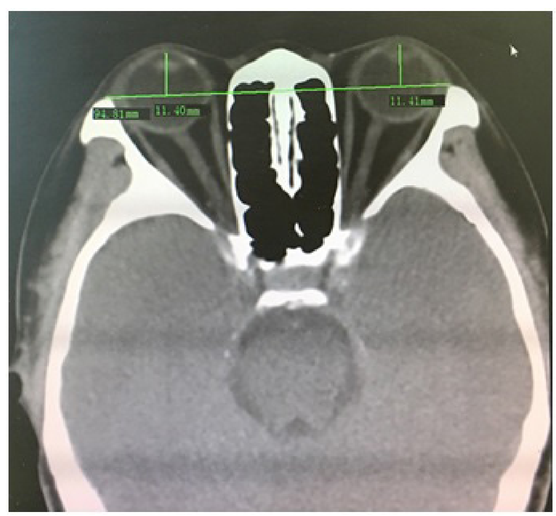

Figure 1: The orbital image measured with computed tomography. The outer margins of both orbits in the soft tissue window were linked to make a line. The vertical line crossing crystal center from the farthest point of front arc of eye ring was made.

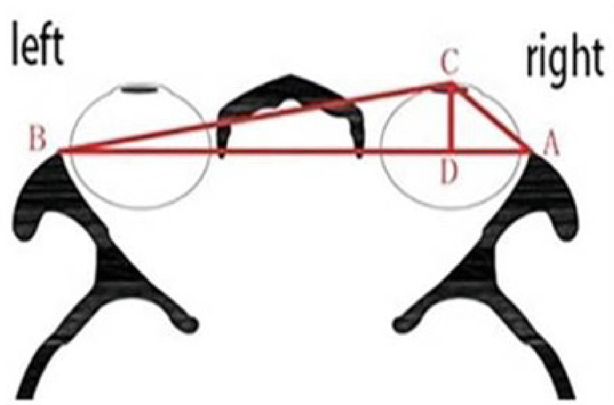

Figure 2: The mathematical model of orbital image based on computed tomography. In triangle ABC, corneal apex and bilateral margins were defined as points C, A and B respectively. And the point D was defined as vertical line from point C crossing line AB. AB = c, AC = b, BC = a and h = CD.

Figure 3: The distance from corneal apex to bilateral orbital margins was measured with Amplitude-mode Ultrasound probe and compasses (A and B). The transverse distance between bilateral orbital margins was also measured (C). All distance was measured with a ruler (D).

3.3. Statistical methods

We used SPSS 19.0 statistical software to check homogeneity test of variance and normal distribution. The value of proptosis measured by CT and trigonometric function were both satisfied. Furthermore, Medcalc software version 19.0.4 was used to conduct Passing-Bablok regression analysis and Bland and Altman plot analysis.

4. Results

The absolute values of right exophthalmos and left exophthalmos measured by CT were 13.38 ± 0.95mm and 13.67 ± 0.70mm respectively, and the relative difference between eyes was 0.68 ± 0.31mm. The absolute values of right exophthalmos and left exophthalmos measured by trigonometric function were 13.35 ± 0.88mm and 13.62 ± 0.68mm respectively, and the relative difference between eyes was 0.62 ± 0.35mm. The regression equation of proptosis in right eye measured by CT and trigonometric function was y = -0.92 + 1.08 x using method of Passing-Bablok regression analysis. Obviously, the slope B is 1.08 (95% CI: 1.00 to 1.19) and the intercept A was -0.92 (95% CI: -2.50 to 0.10). A 95% limit of agreement between CT and trigonometric function was -0.53 to 0.60 mm in right eye proptosis. There was 2.66% (2/60) point outside 95% LoA in right eye (Figure 4I). The regression equation of proptosis of left eye measured by CT and trigonometric function is y = 0.00+ 1.00 x using the Passing-Bablok regression analysis. The slope B is 1.00 (95% CI: 1.00 to 1.14) and the intercept A is 0.00 (95% CI: -1.85 to 1.26E-013). A 95% limit of agreement between CT and trigonometric function method was -0.46 to 0.55 mm in left eye proptosis. There was 1.66% (1/60) point outside 95% LoA in left eye (Figure 4II). The regression equation of difference proptosis is y = 0.10 + 1.00 x between two eyes measured by CT and trigonometric function when using the Passing-Bablok regression analysis. The slope B is 1.00 (95% CI: 0.67 to 1.00) and the intercept A is 0.10 (95% CI: 0.10 to 0.27). A 95% limit of agreement between CT and trigonometric function method was -0.49 to 0.60 mm in difference of both eyes. There were 5% (3/60) points outside 95% LoA (Figure 4III). The points were lower than 5% in all Bland and Altman plots. So we believe that the measurement of proptosis between two methods had a good consistency.

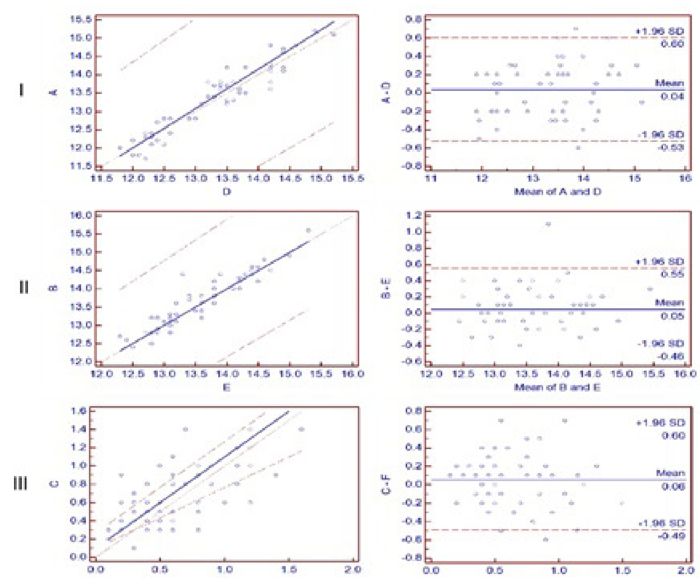

Figure 4: (I) Method comparison of A and D, presented by Passing-Bablok regression analysis (column 1) and Bland and Altman plot, given the confidence interval of 95% (column 2). A and D represent the values of proptosis of right eye measured by CT and trigonometric function respectively. (II) Method comparison of B and E, presented aby Passing-Bablok regression analysis (column 1) and Bland and Altman plot, given the confidence interval of 95% (column 2). B and E represent the values of proptosis of left eye measured by CT and trigonometric function respectively. (III) Method comparison of C and F, presented by Passing-Bablok regression analysis (column 1) and Bland and Altman plot, given the confidence interval of 95% (column 2). C and F represent difference of proptosis between two eyes measured by CT and trigonometric function respectively.

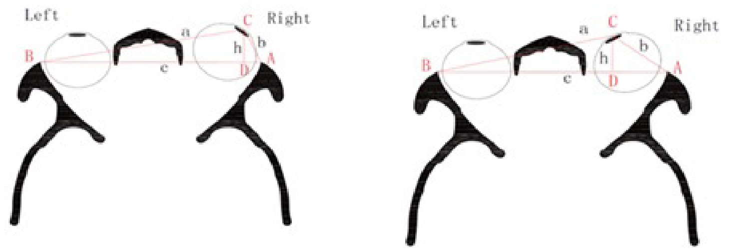

Figure 5: Applying trigonometric function to measure the horizontal non-axial proptosis.

5. Discussions

In our study, we found that there was not different significantly in the measurement of absolute value of proptosis among normal people when using methods of CT and trigonometric function. The relative differences of two eyes were also not significant. It means that the two methods are comparative in accuracy of proptosis measurement.

The method of trigonometric function had high accuracy and repeatability in calculating proptosis. In this study, we used a marker pen to mark the lowest point of outer edge of the orbits as the measurement reference point. The point-to-point measurement which was based on the trigonometric function improved the accuracy of measurement. And the repeatability of measurement reduced errors. The intuitional and accurate data was obtained by orbital CT in measuring proptosis. Although the posterior corneal surface can be identified easily, the eyelid is difficult to distinguish from the anterior the corneal surface in CT. As a result, there is about 0.5mm measurement error of corneal thickness when we measure the proptosis from the posterior surface of the cornea. [3] In addition, it was necessary to find out the scan plane when the lens center (the midpoint between the horizontal and vertical axis of the lens) and the inner orbital segment of the optic nerve were in the same horizontal level in CT measurement. It also requested symmetrical positions of eyes and the lowest point of orbital edge [11]. Consequently, the eye positions and the CT scan plane used for proptosis measurement were inconsistent when repeating the CT examination. Mourits et al. demonstrated that it is highly reliable using Hertel exophthalmometer [6]. However, the data of proptosis might be different among various examiners because of different experience of examiners and the visual errors [12]. Besides, the operating rules and relevant uniform application standards are absented. Some studies found that inexperienced examiners have read less than 1mm than experienced examiners [13].

With simple calculation process, the trigonometric function method was fast and cheap in proptosis measurement and it could be popularized in various occasions. In orbital surgeries, such as the process of ocular protrusion correction and orbital tumors surgeries, the trigonometric function was suitable to calculate the immediate proptosis which could be used for guiding the operation. Although Hertel exophthalmometer can be used to measure proptosis quickly, it needs to purchase the specific measuring instrument. During orbital surgeries, the patients are in supine position after anesthesia, while the measurement of Hertel exophthalmometer requests patients standing upright [14]. As a result, Hertel exophthalmometer is unsuitable for proptosis measurement during operations. Because of radiation damage, high price and need to be analyzed further by software, the application of CT should be avoided due to its time-consuming, expensive-cost, and it cannot be available everywhere. [2, 14]

The trigonometric function method is a less traumatic measurement method to calculate the exophthalmos. In our study, corneal anesthesia and contacting with the cornea were required when the distance from the corneal vertex to the outer edge of orbits was measured. Compared with Hertel exophthalmometer, it seems more traumatic. However, as long as the process of measurement is standardized, it will not cause adverse consequences. With the mobile phone APP infrared measurement software development continuously and the improvement of measurement accuracy, a non-invasive measurement mode using the mobile APP for measurement is possible. CT has unavoidable radiation damage [1] and it cannot be used for pregnant women.

Similarly, the trigonometric function method also needs to refer to the lateral edge of the bilateral orbit. Therefore, the measurement error is relatively obvious in unilateral orbital trauma and dysplasia. The application of preoperative CT and optical 3D imaging technology method have high accuracy in getting the baseline data of proptosis, especially in the patients who suffer from fractures of orbital wall and postoperative follow-up of proptosis. However, wearing contact lens is necessary to avoid infection when conducting optical 3D examination [15]. The above method requires topical anesthesia because of corneal contact. It is necessary to operate carefully and take strict disinfection of the probe to avoid corneal injury.

The degree of sunken eyeball can also be calculated by trigonometric function while the Hertel exophthalmometer cannot with the measurement data. And we believe that it can be applied for the measurement of horizontal non-axial proptosis, too (Figure 5).

In our study, we found that the points we needed to improve were as follows: 1. The data were collected in a single institution; 2. The differences in patient selection and data acquisition could lead to bias; 3. Imperfectly, we should include more cases in our study and the subjects with orbital diseases will be included in our future research.

The operation of trigonometric function is not time-consuming, available and at low-cost. With the improvement of APP infrared measurement software and the improvement of accuracy, the mode using phone APP for proptosis measurement will be non-invasive, cheap, fast and accurate.

6. Conclusions

Compared with Computed Tomography, trigonometric function has a good consistency and can be applied to calculate proptosis. This method is practical in clinical proptosis assessment because it has many advantages, such as reliability, accuracy, simplicity and cost-effectiveness. With the development of APP infrared measurement software and the improvement of accuracy, the mode using phone APP for proptosis measurement will be non-invasive, cheap, fast and accurate.

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